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Developing a Watering System and STEM Educational Materials for a Greenhouse at Turn Back Time Farm and Nature Education Center

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Developing a Watering System and STEM Educational Materials for a Greenhouse at Turn Back Time Farm and Nature Education Center

An Interactive Qualifying Project submitted to the faculty of the Worcester Polytechnic Institute
in partial fulfillment of the requirements for the Degree of Bachelor of Science

Sponsoring Agency: Turn Back Time

Project Advisors:

Professor Elisabeth Stoddard and Professor Ahmet Can Sabuncu

Submitted By:

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Date: June 12, 2019

This report represents work of WPI undergraduate students submitted to the faculty as evidence of a degree requirement. WPI routinely publishes these reports on its web site without editorial or peer review. For more information about the projects program at WPI please see <http://www.wpi.edu/academics/ugradstudies/project-learning.html>

Abstract

Exposure to nature is critical for childhood development. It encourages creativity, problem solving, reduces anxiety, and can enhance academic performance. Turn Back Time in Paxton, MA offers farm and nature-based programs for children. Opportunities for learning are limited in the winter months, when crops are unable to grow. We engineered a water storage and delivery system for a greenhouse under construction to extend the growing season and learning opportunities. We developed STEM educational materials to expand learning in the greenhouse.

Acknowledgments

We would like to thank our sponsor, Lisa Burris, and Turn Back Time (TBT) for providing us with this opportunity to learn about the benefits of nature therapy, and allowing us to help create our own educational activities which will be used at TBT. Burris and TBT's team were very supportive of our efforts throughout the entire project.

Our team would also like to thank Professor Elisabeth Stoddard and Professor Ahmet Can Sabuncu for allowing us to work on this project, and advising our team throughout its entirety.

Additionally, we would like to thank Professor Robert Traver for guiding our team during the initial planning of this project. Professor Traver also assisted our team in creating the educational activities that will be implemented at TBT.

We would also like to thank Donna Taylor, a member of WPI's Stem Education Center, for aiding us in the process of creating and assessing the educational activities that will be implemented at TBT.

Our team would also like to thank the MQP team which worked with us in the planning of the construction of the hoophouse.

Executive Summary

Project goal and objectives

In this project, we worked with our sponsor Lisa Burris at her farm Turn Back Time (TBT). TBT is a 58 acre plot of woodlands and farming areas in Paxton, MA. The Mission statement for TBT is to increase the quality of life for children of all abilities through nature exploration, farm education and play (Burris, 2017). In order to help keep the farming area of TBT equipped with ample amount of water, and the ability to grow crops during an extended season, the goal of this project is to design and implement a rainwater catchment system for a greenhouse, as well as five STEM education activities focused on the greenhouse. This will help the garden and provide context, materials, tools and opportunities needed to help TBT achieve its goals.

In order to achieve our goal we focused on four objectives: 1) determine guidelines and design considerations for the watering systems of the greenhouse, 2) develop design, and create a prototype, and construct internal watering system, 3) determine guidelines and design considerations to develop educational activities connected to the greenhouse, and 4) develop assessment materials to measure learning and developmental outcomes. To accomplish each of these objectives we utilized secondary sources and conducted interviews, as well as utilized the engineering design processes.

Results

A variety watering methods were found. Using a design matrix, we focused on methods that did not require electricity and methods that met requirements given by our sponsor, including watering systems that create opportunities for learning. The final design of the watering system included multiple opportunities for learning, as well as, several delivery methods, all using either hand pumps or gravity to avoid the need for electricity.

The first part of the construction took place at Worcester Polytechnic Institute. The team members drilled a 1.125 inch hole in the barrel. The students then added a bulkhead fitting to ensure the hole was watertight and allowed for a PVC pipe to be connected. The team members also primed and cemented parts of the PVC together to reduce the amount of work which had to be done on the farm.



Andrew Hubina drilling a hole in the storage barrel

Once at Turn Back Time, the team members created a small hole under the greenhouse to allow the PVC pipe to enter the structure without damaging the greenhouse glazing. The barrel was placed outside of the greenhouse, and the water outlet was inside, connected via 1 inch PVC piping. The PVC pipes and the barrel were then primed and cemented together to ensure a watertight seal.



The storage barrel outside of the greenhouse



The water outlets inside of the greenhouse

After communicating with our sponsor, there were some slight modifications that had to be made to maximize the impact this watering system will have on the farm. The PVC pipe was cut to shorten the distance between the barrel and the outlet. The barrel was moved into the greenhouse and the water outlet was moved to a slightly different position in the greenhouse. To maximize the potential energy of the water, a stand was built out of wooden pallets for the barrel and pump to stay on. A box was also made out spare wood on the farm to stop the barrel from tipping over and causing harm to people or the greenhouse. The pump was also screwed into the wooden pallet to stop any movement whilst pumping.



Final design of the watering system



Modification of the wooden pallet to fit the PVC pipe



Box made to hold the barrel in place



Water outlet screwed into the pallet

Conclusion

The project purpose was to develop a rainwater catchment and storage system on a greenhouse in order to help further TBT's nature-based educational programs. Our team also worked to design, build and assessed five educational STEM activities focused on the greenhouse, with the collaboration and mentorship of our sponsors and advisors, as well as expert input from people with knowledge and expertise in early STEM education. Time constraints and concerns from our sponsor limited the development of a fully designed rainwater catchment design, so further development of our final design will have to be made. Additionally, further assessment will be needed, to ensure our five activities continuously meet the needs of the children on the farm. Through this project, we have worked to help TBT enhance its curriculum and provide opportunities for the children to engage in not only nature, but also STEM, and to develop and learn in new ways.

Authorship

Each team member contributed to the writing and revisions of the entirety of this report. We have all reviewed the paper and contributed equally to its various sections.

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1.0 Introduction

Turn Back Time is a 58 acre property, with a small farm, farm animals, nature trails, and a beaver pond located in Paxton, Massachusetts. Turn Back Time aims to increase their crop production, while educating children about nature through hands-on experiences. They currently grow crops for educational and income making opportunities from May-September, the months with the prime growing weather in the New England climate. However, they are interested in increasing their crop production to 10 months of the year to increase educational and income opportunities.

A greenhouse can help to address these problems by extending the growing season and by creating an environment ideal for crops, including ideal temperature and humidity as well as protection from extreme weather. Greenhouses create a much more controlled environment where the plants can thrive. A greenhouse allows solar radiation to enter and it traps the heat inside of the structure raising the internal temperature anywhere from 10 to 50 degrees (Grunert, 2019). Additionally a greenhouse gives a farmer the capability to control temperature through ventilation. This allows the farmer to maintain a temperature optimal for the plants they are growing, something that normally is not possible with the drastic temperature swings in the New England climate (Page, 2019). The rise in temperature within the greenhouse extends the amount of time in a year plants are able to grow. Having the extended growing season will give the kids more opportunity to learn through engaging with and caring for the plants. Our team also created five learning activities for the students to learn science, technology, engineering, and math (STEM) through their interactions with the greenhouse and watering system.

Turn Back Time, as well as other farms in New England face challenges working in a severe climate. New England's climate is an environment which experiences frequent temperature swings from hot to cold, then back to hot, for example this past February it was 10 degrees, then just 4 days later it was a record tying 65 degrees (Page, 2019). The soil at TBT has a high rock and clay content, which is low in nutrients and therefore adds to the difficulty of growing crops (Schulman, 2019). The harsh soil makes it difficult to plant, and increasingly erratic weather makes it harder to plan out planting over a season. As our climate continues to change, New England is expected to see an increase in the frequency and intensity of temperature swings, this can damage crops and be harmful to the farms productions. The results of such as severe loss could put the farm in a deficit which can be very difficult to recover from (Weiskel, 2019). Controlling these variables allows farmers to increase production. They can control variables like humidity and temperature (Roberts, 2017).

Additionally, the presence of a greenhouse at Turn Back Time will create more opportunity for educational activities. The greenhouse will act as a place where children learn STEM related concepts like pressure, light and transparency, heat and cooling, plant growth, and the water cycle through hands-on experiences planting, watering, fertilizing, measuring,

controlling temperature and humidity, and harvesting plants throughout the year for the entire year, not just in the spring and summer months. For example, one of our activities, Greenhouse in a Bag, which involves the children building a miniature greenhouse out of a plastic bag and growing bean seed inside of it. This allows all the children on the farm to learn more about what a greenhouse is and how it works.

The greenhouse at Turn Back Time was designed and built as a Major Qualifying Project by six mechanical engineering students. The MQP team has a larger budget, and was used to offset the cost of the greenhouse for Turn Back Time farm. Therefore, they took the lead on this area of the project. Our IQP project was geared towards designing and building a rainwater catchment system for the greenhouse, to allow the greenhouse to be independent of the farm's other watering needs. This is crucial because, in past years, Turn Back Time suffered from a drought and a lack of multiple water sources to depend upon. The implementation of this system will make them more resilient to future drought, and will increase the number of water sources available to the farm. The result of this project is a system that can capture and store water and is capable of delivering water to the plants in the greenhouse through various methods, including drip tape, the aqua globe, a terracotta pot, the bottle and string method as well as normal hand watering. Additionally, our team created five educational opportunities to be implemented in and around the greenhouse, including greenhouse in a bag, I can eat a whole plant, water pressure testing, water cycle in a bag, and the celery experiment. After the conclusion of both the MQP and IQP projects, the remaining portion of the greenhouse project at TBT that needs to be designed and built is the interior of the greenhouse. The interior design will need to facilitate plant growth and child development.

In this report you will first find a review of the literature on farm-based education and greenhouse design. Second you will find a description of our methodological approach, which involved interviews with our project sponsor, Lisa Burris, and Donna Taylor of the WPI STEM center, as well as an analysis of secondary sources. Third, you will find the results of our research, which includes our findings, design considerations and the final recommendations and building process. Lastly, you will see our conclusions, which highlights the final products of our project.

2.0 Literature Review

2.1 Farm-Based Education and Therapy

Children with exceptional behavioral needs, including those with Attention Deficit and Hyperactivity Disorder and/or those on the Autism Spectrum may have trouble learning and developing critical social skills in a traditional classroom. Many children with exceptional behavioral needs benefit greatly from hands-on physically engaged learning, particularly outside in nature (Connections Therapy Center 2017). Decades of evidence shows that nature-based experiences promotes learning and can help to reduce behaviors, such as aggression, and increase other behaviors, such as concentration (Ambrosini, 2014). Nature-based education, engagement, or therapies can consist of a wide variety of activities related to nature: from going for a walk in the wilderness, or can be as engaging as growing crops (Ambrosini, 2014). The greenhouse and associated watering system at Turn Back Time can provide additional opportunities for children to engage with nature (Connections Therapy Center 2017).

One benefit of exposing children and adults to nature, it that seeing and being in nature has been shown to reduce stress (Ambrosini, 2014). Children with ADHD and those on the Autism spectrum can experience more stress and find it difficult to relieve that stress (Ambrosini, 2014). Nature therapy can also increase self-awareness, which is knowledge of one's desires, motives and feelings (Ambrosini, 2014). Self-awareness for children with ADHD and Autism is important because they are able to gain a better understanding of themselves. Children who are exposed to nature at an early age show an interest in nature-related topics in the future, including STEM, environmental stewardship, animal care, and farming (Connections Therapy Center, 2017). Children with ADHD and Autism often struggle with sensory skills (Ghanizadeh 2010). Sensory skills include tactile sensory, balance control and vestibular systems, auditory sensory, visual sensory, and olfactory function (Ghanizadeh 2010). There are many different smells, feels, sounds and sights which are only found in nature versus in urban settings (Earl, 2018). Through nature and farm-based education, children can develop these essential skills.

Turn Back Time believes that, “play is essential to every child’s development” (Burris 2012). The sponsor’s degree in early childhood education and experience with kids exceptional needs has led her to conclude that a lack of exposure to nature and outdoor play can contribute to or exacerbate Attention Deficit Disorder and Attention Deficit Hyperactivity Disorder (ADD and ADHD) (Burris, 2016). With this in mind, Turn Back Time gears the farm towards the children, with several programs for various age levels, aiming to give children a childhood with access to nature. Some activities currently on the farm include gardening, animal care, crafts and

woodworking, exploratory nature walks, games and music, and photography. The main purpose of all the programs is to get children outdoors (Burris, 2018).

Turn Back Time works to make their programs affordable for everyone through pricing and scholarships, so children who are in families with low incomes will still be able to experience nature through the farm (Burris, In Person Interview, November 18th, 2018). Many of the students of TBT have a difficult time learning in a traditional classroom setting. A typical day at TBT is made up of many hands on activities taking place outside on the farm. This combination of nature and education in a less structured environment has helped the development of many students at TBT (Burris, In Person Interview, November 18,2018).

The addition of a greenhouse will greatly expand the accessibility to outdoor educational activities at Turn Back Time farm. The greenhouse will act as a breeding ground not only for the plants, but for the knowledge of the children on the farm. The greenhouse will bring many learning opportunities to the farm by creating year round access to crops and through activities created by our team, including greenhouse in a bag, I can eat a WHOLE Plant, and the spouting water activity. Lisa Burris mentioned that one problem with nature-based education and therapy is that it is dependant on the weather (Burris, informal conversation, December 2, 2018). One problem that arises is rain. While some kids do not mind being in the rain for hours, not all do. A greenhouse will provide a sheltered location for the children to go during the rain, and still be able to experience the outdoor feeling. Another problem is the cold temperatures during the winter months. It can be dangerous to spend prolonged periods in cold weather due to the chance of frostbite. Since greenhouses have a higher internal temperature than their surroundings, the children on the farm will be able to venture outside of the barn during the winter months (Burris, Informal Conversation, December 2, 2018).

2.2 Using Greenhouses to extend the growing season and protect crops from extreme weather and disease

Greenhouses are one way farmers help boost their production of crops. A greenhouse is a structure which is primarily used to grow plants. They help to ensure that plants receive adequate amounts of heat. A greenhouse is a structure which consists of some structural framing, typically made of either wood or metal, and a translucent material which surrounds the framing. Since they are made of mostly translucent materials, typically glass, plexiglass, or plastic sheeting. They allow sunlight to pass through and get to the plants. Greenhouses also provide plants with heat. When sunlight hits the glass, the solar radiation passes through the glass into the greenhouse. As you can see in the figure below, solar radiation from the sun enters the

greenhouse then is not able to escape back through the translucent material and is trapped inside the greenhouse raising the internal temperature.

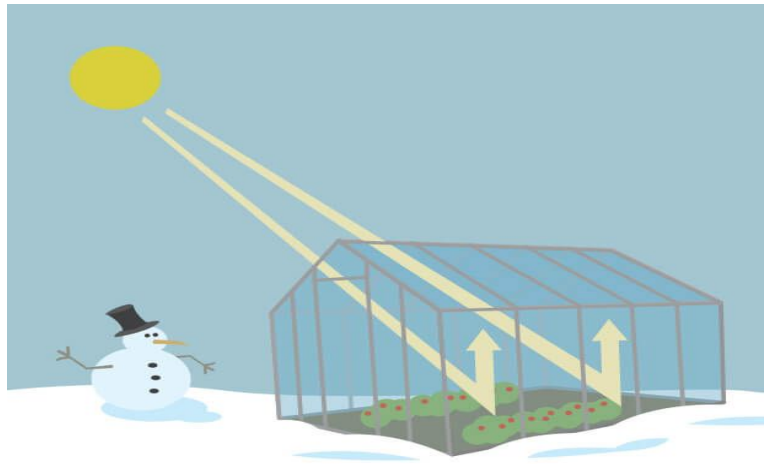


Figure 01: Diagram of how a greenhouse works

Image Source: Doyle, 2019

Once the solar rays reach the soil and plants they get absorbed and reflected. The reflected solar rays travel at a wavelength unique to the rays come directly from the sun (Doyle, 2019). These rays are infrared rays which are not able to pass back through the glass material trapping the energy inside of the greenhouse. This heat then warms the objects inside the greenhouse. The solar radiation that gets trapped in the structure raises the internal temperature this means means that in winter months the temperature inside the greenhouse is 10 to 30 degrees warmer (Grunert, 2019). Since the greenhouse structure is surrounded by its glazing, the heat stays in much longer than if the greenhouse were open to the surrounding environment. This allows the temperature in the greenhouse to get much hotter than the outside air which allows plants to grow inside of the greenhouse even when the external temperatures do not allow it. The farmer has to ensure the temperature inside is not too hot or too cold by using vents to regulate the amount of hot air staying in the greenhouse. In summer months especially the internal temperature of the greenhouse can reach dangerous levels of up to 110 degrees (Grunert,2019). Ventilation is used in order to prevent dangerous conditions inside the greenhouse. Ventilation exists when a portion of the greenhouse is able to be opened to the exterior to allow the air to flow in and out of the greenhouse. This air flow could allow a thermodynamic equilibrium state, where the temperature inside and outside of the greenhouse is the same. Depending on the structure of the greenhouse airflow is such as natural convection will allow for temperature regulation in the greenhouse, allowing the internal temperature to decrease (Hopper, 2012). Farmers also sometimes use artificial heat sources, such as a space heater. This is very useful when sunlight is not sufficient to keep the greenhouse warm. This is especially useful in colder climates, during the winter, and

at nighttime (Connick, 2019). The increase in temperature control for plants allows a farmer to increase their growing season. Conditions for plant growth are able to be made for upwards of 10 months out of the year, in the New England area using a greenhouse (Coleman,1999).

Along with extending the growing season, greenhouses also protect the crops inside from the harsh environment. Since a greenhouse is a structure which shelters plants from external factors, it protects plants from bad weather. Rain, snow, hail and wind all can damage plants. Greenhouses also protect from animals, as insects and animals-such as birds- can damage produce and stunt plant growth. Greenhouses can protect plants from diseases. Since the plants inside a greenhouse do not interact with other plants, the chance of spreading disease is much lower (Bailey,1998). Plants inside the greenhouse have a very controlled environment, which means it only varies slightly. This environment allows farmers to use less chemicals (Bailey,1998). Additionally, plants which are outside of the greenhouse, and therefore more susceptible to disease will not infect the plants inside the greenhouse. The plants inside of the greenhouse are completely separated from those which grow outside of the greenhouse.

2.3 Comparing Mobile and Stationary Greenhouses

The first mobile greenhouse was built in 1898 in England. This green house was built completely out of glass and was transported on steel tracks (chelsagreen.com, 2009). This design has seen many improvements over the years. Today there are two main styles of mobile greenhouses. The more common style is lightweight frame that can easily be moved around. Farmers set this frame up over a section of crops that are already growing in the ground (Moore, 2007). The other model is a trailer that is transported around the farm. Unlike the frame model model this one is completely enclosed, where the plants are grown in pots. The main benefit of the trailer model is that it can be positioned in different areas to optimize the growing needs of the crops inside it(Upgen.org, 2017). Below is an image of a trailer greenhouse.



Figure 02: Trailer Greenhouse
Image Source: Pinterest, 2018

With a traditional, non-mobile greenhouse, mature seedlings must be taken out of the green house and planted in the field. However, with the lightweight frame model, the frame sits over the crops that are growing in the ground. Not only does this save time for the farmer who does not have to transplant the crops, but it is beneficial to the health of the plant. Plants such as; spinach, beets and carrots, have a very delicate root system. If transplanting is not done properly this can be detrimental to the plants health. Other concerns with transplanting is the introduction of other diseases and weeds to the new area (Organicgrowersschool.org, 2018). This style is also the cheapest option out of all greenhouses, mobile or stationary. An image of a frame greenhouse can be found below.



Figure 03: Frame Model
Image Source: bepasgarden.blogspot.com

Targeting the greenhouse to be the best fit at Turn Back Time Farm a decision for which model to build was based off the following criteria; cost, portability, and educational value. These categories were confirmed with our project sponsor (Lisa Burris, December 2, 2018).

Costs associated with the trailer model are greater than the frame model. The trailer model requires a trailer base as well as a more structural frame on top of that. The frame model is made up of a smaller simpler frame that can be made of wood or PVC.

Though the costs are greater the trailer model is considered more portable than the frame model. Being on a trailer one person is capable of moving the greenhouse with the use of a tractor multiple times a day. The frame model is designed to sit over a section of crops that are in the ground. Because of this it would not be useful to move it on a daily basis. Also when it needs to be moved it requires multiple people to carry it.

Using the greenhouse for educational purposes on the farm is very important to our sponsor. A trailer model would allow the students to go inside of the greenhouse. This advantage gives the opportunity to create more lessons for the students. The frame model could be used for educational activities but they are more limited without the opportunity for hands on learning.

Based off the previous reasons the following design/decision matrix was made for the two models.

	Frame Model	Trailer Model
Cost	+	0
Portability	0	+
Education	0	+
Total	1	2

Figure 04: Design/Decision Matrix
Image Source: Andrew Hubina

Based off the design/decision, the trailer model would be the better option for Turn Back Time. Though it would cost more to build its advantages in portability and education would be more beneficial for the farm.

2.4 Conclusion

Throughout the timeframe of this project, the goal has shifted from designing the entire greenhouse, to focusing on developing a watering system which runs off of rainwater, uses no electricity, and creates educational opportunities. The other aspects of the greenhouse have been taken on by a Major Qualifying Project (MQP) team. Worcester Polytechnic Institute provides \$250.00 per student on an MQP Team. This change allowed our sponsor, Lisa Burris, to utilize the financial resources that Worcester Polytechnic Institute provides to MQP teams. The MQP Team used these resources to design the frame of the greenhouse, due to its higher cost than the watering system. This determined that we would be working on another critical system for the greenhouse, the watering system. In the results section, you will find an extensive analysis of greenhouse watering storage, and delivery systems.

3.0 Methodology

Objective 1: Determine Guidelines and Design Considerations for the watering system of the Greenhouse

To meet this objective, we will conduct research in the following categories: 1) water collection methods, 2) water storage methods, and 3) water delivery methods

To collect this data, we utilized both primary and secondary sources. Our primary data collection was through semi-structured interviews with our sponsor Lisa Burris. As the owner of Turn Back Time Farm, Lisa was able to give us the specific criteria that the farm was looking for when designing their greenhouse. Additionally, Lisa was able to tell us what factors were most important to her when considering various designs. For secondary sources, we researched on categories 1-3 through peer-reviewed journal articles, farm organization reports, websites on greenhouse design, greenhouse patents, designs of watering system, and methods for water collection.

Objective 2: Develop Design, Create a Prototype, and Begin Construction of Internal Watering System

In order to construct a well thought out design for the watering system, we used a general engineering design process. This process entails defining the problem, conducting background research, establishing requirements, choosing a solution, planning out and prototyping, and implementing a final design (Norton, Science Buddies).

Defining the Problem

Our first step was to define the problem; what exactly do we need to be solving? Talking with our sponsor, Lisa Burris, provided insight as to what problem(s) she is trying to solve. The primary goal is to provide a solution to how plants in the farm's new greenhouse are to get watered. Having the kids who attend the camp water the plants would be too inconsistent, and a method to automatically keep the plants adequately watered would prevent any plants from being neglected.

Background Research

For the second step in the process, background research from the first objective revealed potential solutions on how others have gone about addressing the same or similar problems.

Secondary research was done on existing watering systems, designs that are already known to work. This revealed the most effective and popular solutions.

As background and preliminary research, we looked into aspects of water catchment systems for both a standard sloped greenhouse roof and a high tunnel system. The article *Rainwater Catchment from a High Tunnel for Irrigation Use* details one possible system for a high tunnel, and we based our comparison off of that system.

In the high tunnel design, as there is no defined roof edge, a height was chosen for where the gutters will be placed. As this will affect the amount of water collected, the amount of water collected versus the gutter height was graphed. This allowed us to choose a height that will provide enough water, should the high tunnel design be selected moving forward.

Additionally, the gutters would need to be able to handle wind and snow loads. From the American Society of Civil Engineers 7-10 (ASCE 7-10) code book, data and procedures were taken in order to calculate what the loads would look like, and how they would affect the gutters.

Establish Requirements

Step three was to establish what the requirements for the project are. To do this, we talked with Lisa Burris to define the requirements for our solution. This narrowed down what sort of systems and solutions are viable, and which would work the best. We asked her to rank some criteria on how important each aspect was to her for this project. Safety, cost, durability, efficiency, education, and maintenance, in that order.

Safety is the first and foremost priority. With children working in and exploring the greenhouse, everything inside needs to be safe for the kids to interact with. As liability for any injury falls to our sponsor, anything we put in the greenhouse needs to be safe. Potential hazards could be in the form of sharp edges on materials or extreme water temperatures. During summer months, the water collecting in the barrels can reach temperatures up to 150°F. This is not safe to come into contact with, so the barrels will be insulated, as well as putting them behind the tables that will be in the greenhouse. That way the barrels will be out of reach, and the insulation provide protection. Material selection and design took sharp edges into account, making sure there are no hazardous parts to the system.

Cost was ranked as second most important. The whole greenhouse is supposed to provide the farm with more efficient means to grow produce to be sold for profit, as well as provide some educational value. If the watering system we develop is too expensive, the actual profit margin will shrink, possibly negating the return on our sponsor's investment. As such, the system cannot use electricity. The installation required as well as the utility cost can be completely avoided by using gravity-fed systems, cutting down greatly on the overall cost. Material selection also factored in to the total cost.

Durability is next in terms of importance. As mentioned previously, children around ages 3-8 years will be in the greenhouse. Kids often don't know their own strength, or how to make sure they aren't going to be damaging something. As a result, whatever system is installed in the

greenhouse must be able to stand up to kids playing and roughhousing. If it breaks or falls apart, the system will end up costing Burris more time and effort, the things she was trying to cut down on. The purpose of this system is to provide reliable watering the plants, so it must not break easily.

Efficiency is the next requirement. The whole need for the watering system is because Burris doesn't have enough time to make sure a whole garden is adequately watered. If the system is going to solve the problem at all, it needs to do it well. Therefore, in this case, we defined efficiency as how well the watering system can do its job. If it is efficient enough, the plants will be adequately watered, but if it is not as efficient, the plants will not be watered as well or as regularly. The kids that visit the farm don't water the plants consistently enough, so the system needs to keep the plants watered just enough. We will talk with a greenhouse manager (as well as the one Burris hires) on how much water the plants would optimally require. We determined the efficiency by what percent difference in water amount the system provides.

The fifth most important requirement is the educational aspect. The watering system is another way to teach kids a variety of topics, from the water cycle, to plant care. A variety of watering methods will easily provide many opportunities for education through hands-on learning.

The last category is maintenance. A hired greenhouse manager will keep track of the plants and the systems in the greenhouse, so things like having to string a soaker hose across the planters is not a huge issue.

Review Solutions

The next step will be to choose the best of the solutions. Options of systems were developed using a design matrix. The designs were presented to Burris, who in turn presented to the Board of Trustees at Turn Back Time. Feedback from both Burris and the Board were taken into consideration when picking the final design.

Objective 3: Determine Guidelines and Design Considerations for Educational Materials and Opportunities

To set up our guidelines, our group held semi-structured interviews with Dr. Robert Traver and Donna Taylor, who is a member of WPI's STEM education center. With the help of both of them, we created a table to break up the goals we had for each activity. We separated the children by ages from 3-4 year olds, 5-6 year olds, and 7-8 year olds. The table also separated the goals into developmental and learning goals. Once this was created, we looked for educational activities that we could create goals for.

To find these, we conducted research on pre-existing educational materials at other nature educational centers. Our team used various resources found online to develop educational activities which satisfy Turn Back Time's needs. Once we had 5 educational activities we used massdoe.edu to find which educational goals that each activity meets.

Once the goals for each activity was recorded, we presented the activities to Lisa Burris at Turn Back Time. She gave us feedback on which ones she thought would work best. She also asked us to create an activity for the older children at the farm, who are ages 9-13. Using the same procedure as stated earlier, we developed another activity to fit the older children of the farm.

Objective 4: Develop Assessment Materials to Measure Learning and Developmental Outcomes

In order to assess the efficiency of the developed material, assessment material was created. Utilizing the educational goals from the activities, learning goals for age group 3-4, 5-6 and 7-8 year olds were defined. These were defined in terms of concepts the students should understand, as well as skills they should be able to use and demonstrate. The STEM Education Center at WPI provided both the education standards (Mass. state and national) to create educational goals, and material on assessing classroom activities.

The material on classroom assessment, *Classroom Assessment for Students Learning*, provides 5 keys to making a quality assessment. These provided the basis to make sure the assessments were suited to the activity, were useful to the teachers, and would accurately represent the learning that takes place in activities. The book also provided a chart on how effective the four types of assessments were for reporting on different aspects. By drawing on the goals for an activity, an assessment type was chosen to report best on what the students would have to learn. For many activities, assessments would be given through students writing in a journal. The sponsor, Lisa Burris, expressed an interest in this sort of assessment as it would fit the classroom setting on Turn Back Time farm but also provide the most formal way to assess students without being boring or disengaging. It would additionally make recording results simpler by providing a place for each student to keep all of their responses, observations and data. Then, the educational and developmental goals were rewritten in context of the activity, with an example of how an instructor would might ask or prompt students. For each prompt, sample answers or responses were given in terms of what the students should understand, or how they should express their learning on the subject. A brief example assessment for the *Greenhouse in a Bag* activity shows how students will learn and be assessed in the activity (see Appendix C).

4.0 Results

4.1 Objective 1 Determine Guidelines and Design Considerations for the watering system of the Greenhouse

Turn Back Time farm needs a greenhouse to have a larger area for the children to play during the colder months as well as have the ability to extend the growing season of their crops. This greenhouse will need a water collection system to capture, store, and deliver water to the plants. Therefore, we researched what design considerations and guidelines make an effective water catchment system for a greenhouse. To achieve this objective we collected data in order to answer the following research questions: 1. How much water does the greenhouse need to operate? 2. Where should we store the water and in what? 3. How to deliver water to the plants? This information was gathered through research utilizing secondary sources, and meetings with our sponsor.

1. How much water does the greenhouse need to operate?

We used local data for average annual rainfall in the Paxton area to determine how much water we would be able to collect (Data, 2019). Based on the structure of the greenhouse being 24 ft x 24ft we calculated ability to collect 15,655.7 gallons of water annually. We then used scientific studies approximating the amount of water per square foot of agricultural area was required (Bartok, 2016). Due to the greenhouse not only being a place to grow plants but also to be an area for kids to learn and play the water needs of the greenhouse are relatively low at only 11,520 gallons per year, which is significantly less than the amount which is able to be captured (Umass Amherst, 2009). In order to ensure the greenhouse is able to supply water when needed to the plants the ability to store water is essential.

2. Where should we store the water and in what?

During our research several water storage options were analyzed. Our initial research from blog posts and other crowdsourcing websites gave us three potential options, a 55 gallon barrel, an IBC tote, and a multi-barrel system.



Figure 05: 55 Gallon Barrel
Image Source: The Cary Company, 2019

The 55 gallon barrel would be the simplest design and would take up the least amount of space. However, the storage capacity is limited to 55 gallons (The Bluebarrel System, 2019).



Figure 06: 275 Gallon IBC tote
Image Source: IBC Tanks.com, 2019

The IBC tote is able to store a greater amount of water, 275 gallons, but takes up more space and in order to reduce the costs we would take it from the current water system leaving that system with only one IBC tote vs the initial design consisting of two IBC totes (Bennelson, 2017).



Figure 07: Multi-Barrel System
Image Source: Solano, 2018

The multi barrel system allows for the storage of more water than the 55 gallon barrel and takes up less space than the IBC tote. The downside to the multi barrel system is the construction of the system is more complex than the other two designs. Price was one of the main interest areas when determining which storage system we should implement. After talking to our sponsor Burris she stated that she already has several barrels on the farm that we could use for our design (Burris, informal conversation, December 2, 2018). After weighing the advantages and disadvantages for each of the three systems we determined the optimal system would be the multi-barrel system. The cost for all the systems is relatively the same, the space required is in the middle and the storage amount is also plenty to supply the greenhouse with the needed quantity of water.

3. How to deliver water to the plants? What water delivery methods should be used?

Burris wants an automated system because it would allow her to spend more of her time focusing on the children and not worrying about the greenhouse and would not add to her workload at the farm (Burris, informal conversation, December 2, 2018). After talking to our sponsor, Lisa Burris, she showed interest in many water delivery systems for educational purposes. This led to research about potential water delivery methods with educational benefits. We explored 6 different irrigation systems, including the drip tape, a soaker hose, the string and bottle method, terracotta pots, the Aqua Globe™, and hand watering.



Figure 08: Drip Tape System
Image Source: Suzanne, 2018

Drip tape is water efficient, because it uses low pressure and slowly drips small amounts of water (Suzanne, 2018). Drip tape is already being purchased for use in the garden, and only cost \$23.49 for 100 ft. However, it can easily become damaged and has a complex installation. Drip tape is made of small tubing designed for columns of plants therefore there are many pieces that contribute to the system(Suzanne, 2018). Additionally, the tubing is fragile as it is so small and could become damaged by children moving it and playing with it.



Figure 09: Soaker Hose
Image Source: Eartheasy.com, 2019

The Soaker hose method is a fragile system which can easily become clogged, provides limited coverage, and is not as water efficient as the drip tape, and cost \$60 to cover approximately 500 square ft. However the soaker hose has an easy installation process and will not wash away the soil.



Figure 10: String and Bottle Watering Method
Image Source: Sullivan, 2018

The string and bottle method consist of a bottle filled with water and string that goes from the water to the soil. This method is beneficial as it can be easily incorporated into STEM concepts, and is basically free of cost. The downside to this system is that the string requires regular replacement and the bottle could easily spill dumping all the water (Sullivan 2018).



Figure 11: Terracotta Pot Watering Method
Image Source: Harland, 2017

The terracotta pot watering method is the most efficient in its water use, as it is a reservoir in the soil which the plants only extract from when they require water (Harland, 2017). However, it requires regular refilling and is difficult to incorporate into the educational system, and would cost approximately \$10 to get a couple small pots.



Figure 12: Aqua Globe
Image Source: AG Distributors & Supplies Corp, 2019

The Aqua Globe™ is traditionally made of glass, which poses a safety hazard. In order to use this system we would need to get a plastic version. A plastic version cost \$10.97 for a package of two. This method is similar to the terracotta pot as it uses the same method of water and is

therefore efficient in its water use and can be used for the educational component of our project, however this also requires to be refilled on a frequent basis.



Figure 13: Watering Can for watering plants by hand
Image Source: A.M. Leanards, 2019

The last system we looked at was basic hand watering, this method requires the most amount of water as the use of this method results in the greatest amount of wasted water, compared to the other systems suggested. Additionally, a watering can requires some basic knowledge about plant needs to avoid over or under watering. The advantage to this system is the children on the farm can actively participate in the watering of the plants and it is cheap as it only requires the purchase of a watering can.

4.2 Objective 2: Develop Design, Create a Prototype, and Begin Construction of Internal Watering System

Engineering Design

In order to develop the design for the watering system the engineering design process was used. Following this process gave a structured outline in developing the final product. This process is outlined as defining the problem, background research, specify requirements, brainstorm solutions, choose the best solution, develop design and communicate results.

Using the guidelines and design considerations found in Objective 1 a design for the watering system was created. Studying past systems a design for a wooden structure and a metal structure prototypes for each were created. A design was created for both since the group designing the structure of the greenhouse was unsure what material the farm would want to use. These prototypes were proposed to the project sponsor, Lisa Burris, and the Board of Trustees for the farm. Based on this a final prototype was made outlining the design as well as construction process.

Design of Gutters

In the original prototype a system needed to be planned for both a wooden greenhouse as well as metal greenhouse. The roof area for both of these options is the same so the water collection calculation in Objective 1 is accurate for both.

Using a study from the University of Massachusetts Amherst Center of Agriculture, Food, and the Environment it was found that a greenhouse needs 0.3 to 0.4 gallons/ square foot of growing area per day on the warmest days (Umass Amherst, 2009). The greenhouse at Turn Back Time will have an area of 576 ft^2 , with an average rainfall of $27.18 \text{ gallons/ft}^2$ (Town of Needham, 2019). If all of the roof space was used $15,655.7 \text{ gallons/yr}$ of rainwater would be collected. Only needing 230.4 gallons/yr at worst case scenario only half of the roof area will be used to collect rainwater.

With the gutters being the same dimensions for the wood greenhouse and the metal greenhouse the snow and wind calculations on the greenhouse were the same. Procedures and data for these calculations was taken from the American Society of Civil Engineers 7-10 (ASCE 7-10) code book. Additional information was taken from The Applied Technology Council (ATC, 2019) and The Commonwealth of Massachusetts (Mass.gov, 2016). Following the procedures in the ASCE 7-10 the wind force was found to be 292.34 pounds of force acting on the face of the gutter and the snow load was 304.92 pounds acting downward on the gutters.

These loads are very comparable to other gutter systems. According to The Commonwealth of Massachusetts the maximum load from snow is 55 lb/ft^2 (Mass.gov, 2016). This load is greater than the national average. In order to minimize deflection in the gutter the screws will be spaced two feet apart, compared to the normal spacing of three and a half feet. Placing the screws closer increases the strength of the gutter (Doityourself.com, 2019). Using the program RISA 2D these loads were added to the gutter. The bending calculations can be found below, units are in lb/ft^2 . Further explanation can be found in Appendix B.

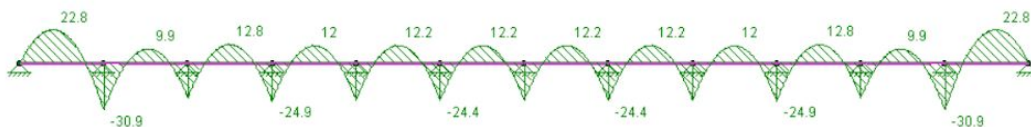


Figure 14: Bending Moment Diagram
Image Source: Made by Andrew Hubina

When screwing into the polycarbonate glaze that covers the greenhouse a certain procedure needs to be followed. Once the location of the screws is known a hole needs to be drilled into the glaze $\frac{5}{64}$ " larger in diameter than that of the screw. When the screw is put in a 1" washer needs to be used. It is important that no screws are within $\frac{1}{2}$ " of the edge of the glazing (Rimolgreenhouses.com, 2019). Following this procedure will prevent any tearing in the glazing due to the screws.

For the wooden greenhouse these screws can be attached directly to the frame of the structure. On the inside of the gutter a gutter hanger must be used. The screw goes through one end of this piece, and the other hooks into the other end of the gutter. A picture can be found below.



Figure 15: Gutter Hanger Installation
Image Source: guttersupply.com, 2019

Attaching the gutters to a metal greenhouse will require more steps. First a 2 x 4 needs to be cut at an angle to increase the area connecting to the greenhouse. Boards should be the length of the spacing rods of the greenhouse. See the diagram below for a visual on how to cut the boards (Iowa State University, 2012).

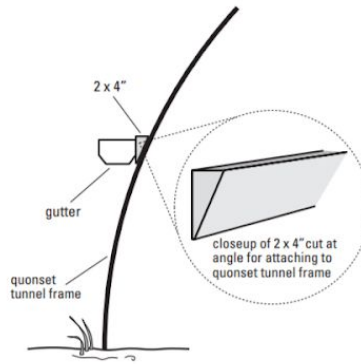


Figure 16: Gutter Support Board
Image Source: Iowa State University, 2012

Conduit straps are used to connect the supporting boards to the metal rods of the greenhouse, on the inside of the vinyl cover. The strap goes around the metal rod and then is screwed into the supporting boards on each side. An example for how this should be done can be found below.



Figure 17: Conduit Strap Installation
Image Source: Iowa State University Extension and Outreach Youtube Channel, 2013

Once the board is installed on the inside of the greenhouse, the gutters can be screwed into the board from the outside the same way as a wooden greenhouse.

Water Filtration

When collecting rainwater the first flush from the roof contains most of the bacteria. To filter this water out a water diverter will collect the initial water. This diverter works by collecting the initial water in a downspout. As the water fills this downspout a ball floats to the top with the

water level. When this ball reaches the top it blocks off the downspout and the remainder of the water travels to barrel. Between collection periods a cap needs to be removed from the downspout to clear out the water (rainharvest.com, 2019). A picture of this system can be found below.

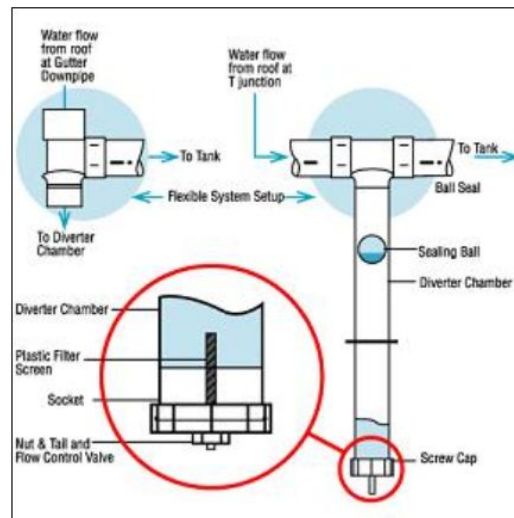


Figure 18: Water Diverter
Image Source: rainharvest.com, 2019

Barrel System

After visiting Turn Back Time farm it was decided that the 125 gallon barrel the farm was not using would be the best fit for the project. It would be big enough to hold the water by itself but not take up as much room as the IBC tote.

The barrel will be stored inside the greenhouse in a corner along the north wall. This allows for the barrel to absorb the most thermal energy from the sun since the barrel will be exposed to sunlight for a longer period of time. The water will then release this heat overnight to help warm the greenhouse during colder periods (Bridgnell, 2017).

Water Pump

In order to deliver the water from the storage apparatus to the plants a pump needs to be used. When looking at various pumps the key features that are important to our sponsor are ease of use for the children as well as cost. Our research on water pumps for the barrels resulted in 3 options, a crank pump, and two types of lever pumps. The crank pump is inexpensive and is easy for an adult to use, however, due to the fact that the pump must be cranked from the top of the barrel it makes it difficult for the children to get access to the pump mechanism. One of the two lever pumps exhibit the same traits of the crank pump. The third pump, lever pump is the most

expensive pump at \$76 however the pump exits the barrels at ground level which will allow the children to easily have access and be able to pump the water themselves. According to the calculations in Appendix A, you can see that the kids will easily be able to manipulate the pump.

4.3 Objective 3 Determine Guidelines and Design Considerations to Develop Educational Activities Connected to the Greenhouse

Turn Back Time not only is looking for a greenhouse to increase crop production, but also to help educate children. The educational activities will focus on crop lifecycles, how greenhouses work, and various watering methods. Guidelines for each educational activity were created. It is beneficial to use the Massachusetts State Standards (Taylor, In Person Interview , January 23rd, 2019). By using the information on www.doe.mass.edu the guidelines created to ensure that the students will obtain the maximum benefit from these lessons. The rubrics show the various developmental and educational goals for the different age groups. The age groups we will be separating the children into are, three and four year olds, five and six year olds, and seven and eight year olds. The rubrics and descriptions for each activity is shown below.

Greenhouse in a Bag

Description: Lesson on how greenhouses work. Each student will make a mini greenhouse out of a plastic bag and grow beans on the inside. Each student will make observations on the growth in their own journal. Only takes three to five days for the beans to start to grow.

Procedure: First step is to make a paper greenhouse frame. This is not required, but is aesthetically pleasing.



Figure 19: Paper Greenhouse Frame
Image Source: Science 4 Superheroes, 2015

Put one cup of potting soil in a ziplock bag. Add water to the soil until it is moist but not wet. Add two beans and fully submerge them in the soil. Seal the bag.



Figure 20: Ziplock bag with potting soil
Image Source: Science 4 Superheroes, 2015

Tape the bag to the back of the construction paper so the bag is visible from the front.



Figure 22: Behind view of Greenhouse in a bag
Image Source: Science 4 Superheroes, 2015

Place in an area with sunlight and wait!



Figure 23: Greenhouse in a Bag final product
Image Source: Science 4 Superheroes, 2015

Materials: Ziploc bag, bean seeds, potting soil, scissors, water, construction paper, markers, ruler, tape

Timeframe: Build ‘greenhouse’ one hour, plant growth can be noticed in three to five days

Found at: <https://science4superheroes.wordpress.com/2015/05/21/ziplock-greenhouse/>

Table 1 lists the learning and developmental outcomes of the Greenhouse in a Bag activity for children ages 3-8. This information comes from the Department of Elementary and Secondary Education, which are standards prepared by the commissioner, Mitchell D. Chester, Ed.D. and is used for the Commonwealth’s public schools to ensure students are prepared for success in college, career, and civic life.

Age Group (years)	3-4 (Pre-K)	5-6 (Kindergarten-1st)	7-8 (2nd-3rd)
Developmental Goals	<ul style="list-style-type: none"> Students sort materials by simple observable properties such as texture and color Students share their understanding of these concepts through discussion as they develop their language and quantitative skills. 	<ul style="list-style-type: none"> Students will learn to use observations as evidence to support a claim through growing language skills. 	<ul style="list-style-type: none"> Students use their observational skills gained in earlier grades to classify materials based on similar properties and functions. Students gain experience testing different materials to collect and then analyze data for the purpose of determining which materials are best for a specific

			function
Learning Goals	<ul style="list-style-type: none"> • Use observations to explain the young plants and animals are like but not exactly like their parents (PreK-LS3-1-MA, 2016). • Use observations to recognize differences and similarities among themselves and their friends (PreK-LS3-2-MA, 2016). 	<ul style="list-style-type: none"> • Observe and communicate that animals and plants need food, water and air to survive. Plants make their own food and need light to live and grow (K-LS1-1, 2016). • Recognize that all plants and animals grow and change over time (K-LS1-2-MA, 2016). • Conduct an investigation to determine the effect of placing materials that allow light to pass through them, allow only some light through them block all of the light or redirect light when put in the path of a beam of light (1-PS4-3, 2016). 	<ul style="list-style-type: none"> • Describe and classify different kinds of materials by observable properties of color, flexibility, hardness, texture absorbency (2-PS1-1, 2016). • Analyze data from tests of two objects designed to solve the same design problem to compare the strengths and weaknesses of how each object performs (K-2-ETS1-3, 2016).

Table 1: Learning and Developmental Outcomes for Greenhouse in a Bag Activity

Water Cycle in a Bag

Description: Preschool lesson on how the water cycle works. Each student will make a mini water cycle in a plastic bag. Each student will make observations on the changes of the water in the bag in their own journal.

Procedure: The First step is to decorate the ziplock bag. This step is purely aesthetic but helps the children keep interest and gain a better understanding. Draw a cloud and a sun.



Figure 24: Decorating the Ziplock Bag

Image source: Mobile Ed Productions, 2016

Next, get a cup of water and add food coloring until it is dark enough. Add the water to the ziplock bag and seal the bag.



Figure 25: Pouring the water and food coloring into the bag
Image source: Mobile Ed Productions, 2016

The final step is to tape the bag to a window. Changes to the water can happen in as early as an hour. Have the children observe the bag for a week.



Figure 26: Water Cycle in a Bag Final Product
Image source: Mobile Ed Productions, 2016

Materials: Ziploc bag, black sharpie, water, food coloring, clear tape

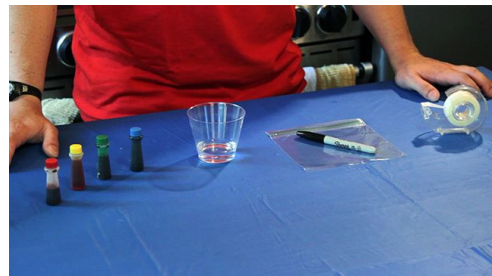


Figure 27: Supplies needed for Water Cycle in a bag Activity
Image source: Mobile Ed Productions, 2016

Timeframe: 1 week (dependent on how warm it is outside)

Found at: <https://www.mobileedproductions.com/blog/how-to-make-a-water-cycle-in-a-bag>

Table 2 lists the learning and developmental outcomes of the Water Cycle in a Bag activity for children ages 3-8. This information comes from the Department of Elementary and Secondary Education, which are standards prepared by the commissioner, Mitchell D. Chester, Ed.D. and is

used for the Commonwealth's public schools to ensure students are prepared for success in college, career, and civic life.

Age Group (years)	3-4 (Pre-K)	5-6 (Kindergarten- 1st)	7-8 (2nd-3rd)
Developmental Goals	<ul style="list-style-type: none"> Students focus on experiencing and making observations of the world around them. They share their understanding of these concepts through discussion as they develop their language and quantitative skills. 	<ul style="list-style-type: none"> Students begin to learn to use these observations as evidence to support a claim through growing language skills. 	<ul style="list-style-type: none"> Students reason and provide evidence to support arguments for the influence of humans on nature and nature on human experience.
Learning Goals	<ul style="list-style-type: none"> Use simple instruments to collect and record data on elements of daily weather, including sun or clouds, wind, snow or rain, and higher or lower temperature (PreK-ESS2-4-MA, 2016). Describe how local weather changes from day to day and over the seasons and recognize patterns in those changes (PreK-ESS2-5MA, 2016). 	<ul style="list-style-type: none"> Make observations to determine that sunlight warms materials on Earth's surface (K-PS3-1, 2016). Conduct an investigation to determine the effect of placing materials that allow light to pass through them, allow only some light through them, block all the light, or redirect light when put in the path of a beam of light (1-PS4-3, 2016). 	<ul style="list-style-type: none"> Use graphs and tables of local weather data to describe and predict typical weather during a particular season in an area (3-ESS2-1, 2016). Analyze data from tests of two objects designed to solve the same design problem to compare the strengths and weaknesses of how each object performs (2.K-2-ETS1-3, 2016).

Table 2: Learning and Developmental Outcomes for Water Cycle in a Bag Activity

Celery Experiment; How Plants Absorb Water

Description: This lesson will show the growth of plants, as well as the need for water. Food coloring can be added to show the path of water in the plant.

Procedure: Ahead of the lesson, have celery stalks prepare. Start with a whole stalk and remove the outer, older stems starting at half an inch up from the base, leaving the younger leafy stems in the center intact. This is the part that will grow into the new plant. The base of the plant should then be cut so that the base (up to 1/4 inch up the plant) is in quarters. This can also be done on celery stalks without a base, but the process will take a bit longer.



Figure 28: Celery before Changing Color
Image Source: Teaching Tiny Tots

Take a container for each student. Containers can then be decorated by students, perhaps with drawings of plants or things plants like. Then, the celery may be put into the containers, with food coloring and water added. The water level should be enough to cover the base of the plant, but overwatering is not a huge concern.



Figure 29: Celery changing color
Image Source: Teaching Tiny Tots

Materials: Celery plants, small containers; plastic is suggested, water, food coloring
Timeframe: Decorating containers and setting up plants would take around 30 minutes. Slight results will be shown within a few hours, but after two days the full impact will be shown.
Found at: <http://www.teaching-tiny-tots.com/toddler-science-celery-experiment.html>

Table 3 lists the learning and developmental outcomes of the Celery Experiment; How Plants Absorb Water activity for children ages 3-8. This information comes from the Department of Elementary and Secondary Education, which are standards prepared by the commissioner, Mitchell D. Chester, Ed.D. and is used for the Commonwealth’s public schools to ensure students are prepared for success in college, career, and civic life.

Age Group (years)	3-4 (Pre-K)	5-6 (Kindergarten- 1st)	7-8 (2nd-3rd)
Developmental Goals	<ul style="list-style-type: none"> Students can identify and use colors creatively Students recognize growth over time and that the plant needs water, as well as human needs that are drawn from plants (I can eat celery, etc). They will express this both visually with drawing and also through discussion. 	<ul style="list-style-type: none"> Students will learn to use observations as evidence to support a claim through growing language skills Students will recognize plant growth as well as the methods through which a plant satisfies its needs 	<ul style="list-style-type: none"> Students use observational skills to recognize various stages of plant growth, as well as quantify the growth they are seeing using basic tools or references (It grew one thumb-length) Students can draw a depiction of the plant, labelling parts and functions of parts
Learning Goals	<ul style="list-style-type: none"> Compare, using descriptions and drawings, the external body parts of plants and explain functions of some of the observable parts (PreK-LS1-1MA, 2016). Using evidence from the local environment, explain how the plants meet their needs where they live (PreK-LS2-2MA, 2016). 	<ul style="list-style-type: none"> Observe and communicate that plants need water and light to survive. Plants make their own food and need light to live and grow (K-LS1-1, 2016). Recognize that all plants grow and change over time (K-LS1-2-MA, 2016). Use information from observations (first-hand and from media) to identify similarities and differences among individual plants of the same kind (1-LS3-1,2016). 	<ul style="list-style-type: none"> Develop and use models to compare how plants and animals depend on their surroundings and other living things to meet their needs in the places they live (2-LS2-3-MA, 2016).

Table 3: Learning and Developmental Outcomes for The Celery Experiment: How Plants Absorb Water Activity

I Can Eat a WHOLE Plant

Description: Students will put together various fruits and vegetables to assemble a “whole” plant. They will learn about each part of the plant and its function.

Procedure: Acquire at least one type of plant from each column. Put the fruits and vegetables at a centralized location.

ROOTS	SEEDS	LEAVES	STEMS	FLOWERS
CARROT	SUNFLOWER SEEDS	LETTUCE	CELERY	BROCCOLI
RADISH	CORN	SPINACH	ASPARAGUS	CAULIFLOWER

Table 4: Acceptable Vegetables for each component of I Can Eat a WHOLE Plant Worksheet

Give each student a worksheet. Describe the role of each part of a plant labeled on the worksheet. After, allow the students to grab the produce to fill in their worksheet. Once completed, allow them to enjoy their plant as a healthy snack!

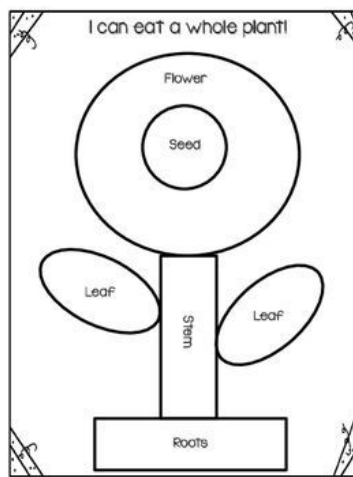


Figure 30: I Can Eat a WHOLE Plant Worksheet

Image Source: The Therapeutic Teacher, 2015

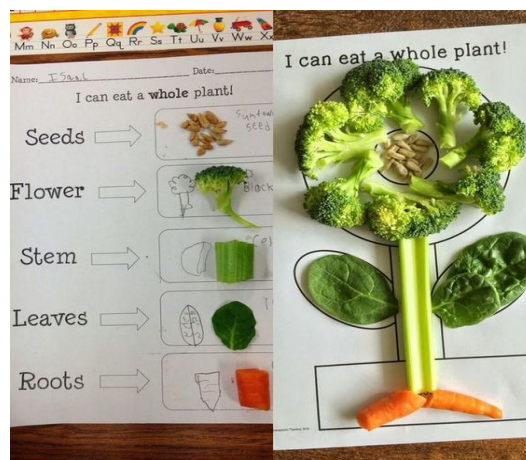


Figure 31: Example of Completed Activity

Image Source: The Therapeutic Teacher, 2015

Materials: Various vegetables, worksheets

Timeframe: One Hour

Found at <http://thetherapeuticteacher.blogspot.com/2015/04/its-plant-time.html>

Table 5 lists the learning and developmental outcomes of the I Can Eat a WHOLE Plant activity for children ages 3-8. This information comes from the Department of Elementary and Secondary Education, which are standards prepared by the commissioner, Mitchell D. Chester, Ed.D. and is used for the Commonwealth's public schools to ensure students are prepared for success in college, career, and civic life.

Age Group (years)	3-4 (Pre-K)	5-6 (Kindergarten- 1st)	7-8 (2nd-3rd)
Developmental Goals	<ul style="list-style-type: none">Students can identify various parts of plants	<ul style="list-style-type: none">Students will learn to use observations as evidence to support a claim through growing language skills	<ul style="list-style-type: none">Students use observational skills to recognize various stages of plant growth, as well as quantify the growth they are seeing using basic tools or references (It grew one thumb-length)Students can draw a depiction of the plant, labelling parts and functions of parts
Learning Goals	<ul style="list-style-type: none">Use evidence from animals and plants to define several characteristics of living things that distinguish them from non-living things (PreK-LS2-1-MA, 2016).Using evidence from the local environment, explain how familiar plants and animals meet their needs where they live (PreK-LS2-2-MA, 2016).	<ul style="list-style-type: none">Use evidence to explain that plants have roots, stems, leaves, flowers, and fruits that are used to take in water, air, and other nutrients, and produce food for the plant (1-LS1-1, 2016).	<ul style="list-style-type: none">Use simple graphical representations to show that different types of organisms have unique and diverse life cycles. Describe that all organisms have birth, growth, reproduction, and death in common but there are a variety of ways in which these happen (3-LS1-1,2016).

Table 5: Learning and Developmental Outcomes for I Can Eat a WHOLE Plant Activity

Propagation of a Plant

Description: Children learn how plant propagation works, and how cutting certain places of some plants allows you to turn one plant into multiple plants. This activity teaches children about root development, plant growth, and plants needs.

Procedure: Cut the plant into multiple pieces, ensuring that each part has a stem. Place the cut up plant parts into soil or water. Wait for the plant to begin to propagate. Explain to the children what is happening as changes to happen to the plant. Have the students record their observations in a journal.

Materials: Water Bottles, moistened soilless potting mix, water, scissors, stock plants (coleus, pothos ivy, geraniums or wandering jew)

Timeframe: 30 minutes activity time, 3 - 4 weeks for growing

Found at: <https://kidsgardening.org/lesson-plans-asexual-propagation/>

Table 6 lists the learning and developmental outcomes of the Propagation of a Plant activity for children ages 3-8. This information comes from the Department of Elementary and Secondary Education, which are standards prepared by the commissioner, Mitchell D. Chester, Ed.D. and is used for the Commonwealth's public schools to ensure students are prepared for success in college, career, and civic life.

Age Group (years)	3-4 (Pre-K)	5-6 (Kindergarten- 1st)	7-8 (2nd-3rd)
Developmental Goals	<ul style="list-style-type: none"> Students will develop their fine motor skills by digging small holes for the plants 	<ul style="list-style-type: none"> Students will develop their fine motor skills by placing the plants into holes in the soil 	<ul style="list-style-type: none"> Students will develop their fine motor skills, and experience with using tools by cutting the plants into sections
Learning Goals	<ul style="list-style-type: none"> Use observations to explain that young plants and animals are like but not exactly like their parents (PreK-LS3-1-MA, 2016). Compare, using descriptions and drawings, the external body parts of animals (including humans) and plants and explain the functions of some of the observable body parts (PreK-LS1-1-MA, 2016). 	<ul style="list-style-type: none"> Use information from observations (first-hand and from media) to identify similarities and differences among individual plants or animals of the same kind (1-LS3-1, 2016). Recognize that all plants and animals grow and change over time (K-LS1-2-MA, 2016). Observe and communicate that animals (including humans) and plants need food, water, and air to survive. Animals get food from plants or other animals. Plants make their own food and need light to live and grow (K-LS1-1,2016). 	<ul style="list-style-type: none"> Develop and use models to compare how plants and animals depend on their surroundings and other living things to meet their needs in the places they live (2-LS2-3-MA, 2016).

Table 6: Learning and Developmental Outcomes for Propagation of a Plant Activity

Most of the children at Turn Back Time fall into the age range of 3-8. There are some children who are as old as 13. In order to include every student at the farm, some of the educational activities need to have additional components which are relevant to the educational standards for those age ranges (Burris, In Person Interview, April 1st, 2019).

The five educational activities shown above were presented to Lisa Burris on April 1st, 2019. She enjoyed all of them, and believed that they could all be implemented at Turn Back Time. In order to satisfy the educational standards for the age range of 9-13, she asked for add-ons to be made to the Greenhouse in a Bag activity and the I can Eat a WHOLE Plant activity. The add-ons would allow the younger children to participate in the lesson, and keep the attention of the older children at the farm (Burris, In Person Interview, April 1st, 2019).

Due to the large age range, it is hard to create an activity that is simple enough for the younger children, and also benefits the older children. In order to combat this, an additional activity was created specifically for the children on the farm between the ages of 9-13. In the future, if Lisa Burris would want to add more activities, there are many resources about teaching with a greenhouse available, such as

<http://lasp.colorado.edu/home/wp-content/uploads/2011/08/The-Greenhouse-Experiment.pdf>.

Spouting Water Activity

Description: This activity is a cheap and quick way to show the impact water pressure has. Students will be able to see the change in distance of water shooting out of a hole with changes in water pressure.

Procedure: To start, you need to create three holes on the side of a 2 liter soda bottle. To do this, heat up a small nail with a candle or a hot pad. Once the nail has been heated up, use the nail to poke the three holes into the soda bottle. The first hole should be about 2 inches from the bottom of the bottle. The next two holes should be roughly 2.5 inches apart from each other. Attempt to make them in as straight a line as possible. Once the three holes have been made cover them with tape. Once the holes have been covered, fill the bottle with water and put the cap back on. Before removing the tape, have the students guess which hole they believe the water will shoot out the farthest from. After they have made their guesses, remove the cap and tape. Watch as the distance of the water changes as the water level falls.



Figure 32: Water shooting out of the holes

Image Source: Kids Fun Science

Materials: 2 Liter soda bottle, water, a small nail, hot pad or candle, plastic container, tape, and something to hold the bottle above the plastic container.

Timeframe: 30 minutes

Found at: <http://www.kids-fun-science.com/kids-science-activities.html>

Table 7 lists the learning and developmental outcomes of the Spouting Water Activity for children ages 9-13. This information comes from the Department of Elementary and Secondary Education, which are standards prepared by the commissioner, Mitchell D. Chester, Ed.D. and is used for the Commonwealth's public schools to ensure students are prepared for success in college, career, and civic life.

Age Group (years)	9-10 (4th-5th)	11-13 (6th-8th)
Developmental Goals	<ul style="list-style-type: none"> Students will use their critical thinking to make a hypothesis about what will happen. 	<ul style="list-style-type: none"> Students will be able to use what they have learned in previous courses to explain why the events that occurred during the activity happened.
Learning Goals	<ul style="list-style-type: none"> Support an argument with evidence that the gravitational force exerted by Earth on objects is directed toward Earth's center (5-PS2-1). 	<ul style="list-style-type: none"> Provide evidence that the change in an object's speed depends on the sum of the forces on the object (the net force) and the mass of the object (8.MS-PS2-2).

Table 7: Learning and Developmental Outcomes for the Spouting Water Activity

The enjoyment of the children is also crucial to a meaningful lesson. The activities all aim to not only teach children, but also entertain them. It is also important to have groups of two or three children for these activities, as it ensures that no one is left out. Engagement leads to more educational value. Another aspect of these educational activities is the children's attention

span. Donna Taylor suggested plants that grow relatively quickly to keep kids entertained, such as sweet peas (Taylor, In Person Interview, January 23rd, 2019).

4.4 Objective 4: Develop Assessment Materials to Measure Learning and Developmental Outcomes

The quality of the educational materials needs to be assessed, in order to ensure the activities meet the standards and goals. Consulting with experts in the education field, like Assistant Director of Professional Development, Donna Taylor, will provide us with both characteristics of a successful trial, as well as materials to ensure sound design and purpose for assessments.

Taylor also advised us on how to assess our material. The first step would be to know what optimal results are, either a baseline or an overall goal for the educational material to achieve. The developmental and learning goals (Massachusetts D.O.E. education guidelines) provide a basis of what an activity hopes to provide for the students. Therefore, any assessment of an activities success should look at first what goals are relevant to it, and then judge how well the goals are met (Taylor, In Person Interview, January 23rd, 2019).

Taylor suggested ways in which to collect data and observations, so that there would be distinct results to analyze. These parts focus on the design of the educational activities, so that more tangible and accessible results are available. Activities like modelling focus around producing such results, but other activities need some way for students to reflect on the purpose of the activity. Suitable methods might take the form of drawing. Drawing is an engaging activity for most students, and can be used to have students model a system or concept from an activity. Labelling or other explanation of the drawings can demonstrate the student's understanding. Keeping a journal is a good way to provide results in writing. A more direct assessment can be used by asking the students to write about what they learned or the concepts of the educational materials. (Taylor, In Person Interview, January 23rd, 2019). The book *Classroom Assessment for Student Learning* provides a lot of material specifically on assessing educational activities. Taylor provided several excerpts which helped give framework to designing assessments. The book uses *5 Keys to Quality Assessment* to define a good assessment.

FIGURE 1.3 Keys to Quality Classroom Assessment

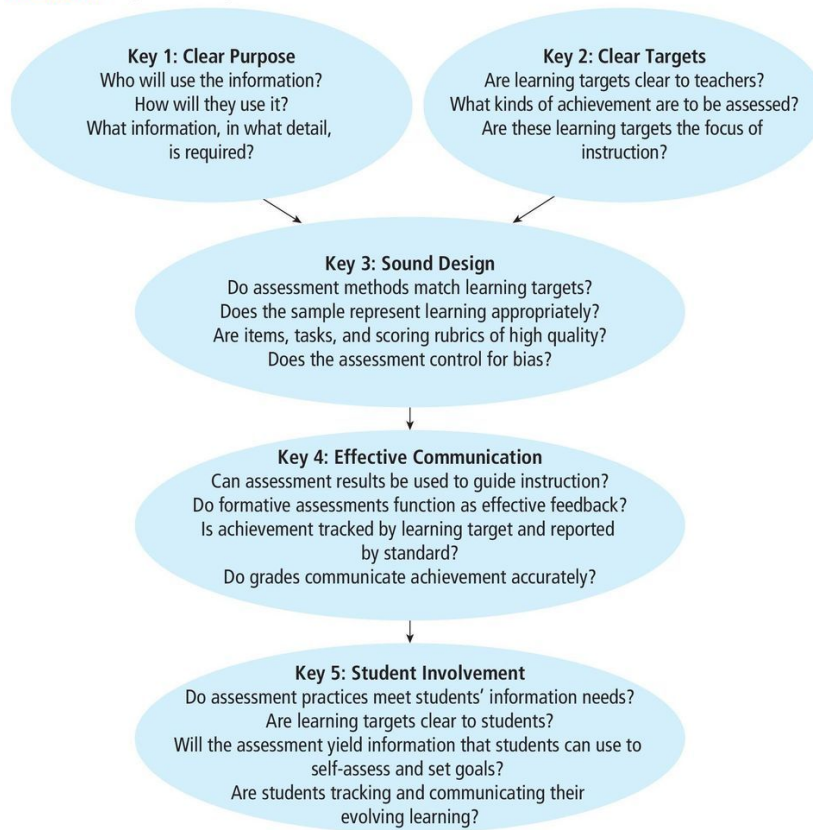


Image Source: Classroom Assessment for Student Learning

The first key asks what information is needed, by who, for what purpose. The purpose is clear, as noted in the book. "...We rely on classroom assessment evidence...to determine how much learning has occurred. (Chappuis)" The information itself will be responses from the students, in various forms, to convey how much the students learn and understand. Teachers at Turn Back Time will use this to see how well students learn from activities, and to adjust the activities where necessary.

The second key involves the goal, or learning targets. There must be a directive, a point or concept for the instruction to convey. These are very easy to characterize by using educational standards, designed to provide such targets to teachers. The Massachusetts Department of Education's educational standards were used as the learning targets for the educational material, with levels of understanding set for different age groups. As activities were refined, so were the learning targets, narrowing down to only the most relevant ones. This ensures that learning targets are the focus of the activities. By having the material focus on subjects that pertain to the goals, and having assessments that check if the learning goals are being met, the objectives will be clear to the teachers.

The third key is the most important point for designing assessments themselves. It deals directly with making an accurate and effective assessment methods. There are four separate methods for assessing or testing: selected response, written response, performance assessment, and personal communication. Each of these methods has strong and weak points for assessing different things.

Figure 4.2 Target-method Match

	Selected Response	Written Response	Performance Assessment	Personal Communication
Knowledge	Good Can assess isolated elements of knowledge and some relationships among them	Strong Can assess elements of knowledge and relationships among them	Partial Can assess elements of knowledge and relationships among them in certain contexts	Strong Can assess elements of knowledge and relationships among them
Reasoning	Good Can assess many but not all reasoning targets	Strong Can assess all reasoning targets	Partial* Can assess reasoning targets in the context of certain tasks in certain contexts	Strong Can assess all reasoning targets
Skill	Poor Cannot assess skill level; can only assess prerequisite knowledge and reasoning	Poor Cannot assess skill level; can only assess prerequisite knowledge and reasoning	Strong Can observe and assess skills as they are being performed	Partial Strong match for some oral communication proficiencies; not a good match otherwise
Product	Poor Cannot assess the quality of a product; can only assess prerequisite knowledge and reasoning	Poor* Cannot assess the quality of a product; can only assess prerequisite knowledge and reasoning	Strong Can directly assess the attributes of quality of products	Poor Cannot assess the quality of a product; can only assess prerequisite knowledge and reasoning

* = modification

Image Source: Classroom Assessment for Student Learning

Selected Response is a multiple choice type of assessment. When presented with a question and several possible answers, students *select* the option they find to be the most correct answer. This could come in the form of, for example, a multiple choice quiz, or matching game. This suits the classroom environment of Turn Back Time farm well, as it can adapt well to games and matching activities.

Written Response is an independent assessment. Students will provide their own answers and explanations to a question. This writing could come in the form of a written response of a formal test or quiz, or a more relaxed form such as writing a quick response in a journal.

Performance Assessment is a method in which students demonstrate something actively, such as creating something, completing a task, or utilizing tools. The students perform skills to show what they have learned. While this doesn't work well with demonstrating knowledge of concepts, it does suit the farm setting well, by letting students be more hands on and active.

Personal Communication is a method where students verbally express an answer. Students can use and develop their communication skills, providing an explanation in their own words. By giving an explanation in familiar language, students express just how well they have learned a concept. Plus, it

doesn't require any writing or tasks that might prove disengaging. Prompts provided in an activity help direct such communication.

Key four is effective communication; how do the results appear? Do the results help report on if the students are achieving the goals, and help guide instruction? Each activity is designed around the learning goals, as are the assessments. By framing the assessments in terms of what achieving the goals should look like, whatever reports are made using the assessments will be reporting specifically on how well students meet those goals, and grasp those concepts.

The fifth and last key is student involvement. Do students understand the goals of the activity, and are they engaged in the learning that takes place? For all the pieces to work together, the students have fit in as well. If the assessment doesn't fit with the activity, students will lose interest in it. Therefore, the more formal methods of assessment don't fit the setting. An outdoors and hands-on activity is far more exciting than taking a test, no matter how short. Any assessments that involve writing or answering questions need to be framed in an engaging way in order to keep students' attention. By working writing or questions or prompts into the activities, students will remain engaged, while thinking about the concepts a bit at a time, in short parts.

These keys were used to create assessments for each activity, as follows.

Activities Assessments:

Greenhouse In A Bag

Students are tasked with creating their own greenhouse out of a plastic bag, with simple materials to decorate it. Then they will leave a plant like a bean inside, and make observations as it begins growing. The increasing age groups will have increasingly in-depth or advanced concepts taught.

	Development	Content
3-4	Simple observations like color and texture Fine motor skills for arts and crafts Recognizing what makes plants different	Colors, shapes and textures What do plants like?
5-6	Observing and comparing Measuring growth Making a claim about the plant's progress, using observations to support it Discuss what the parts of a greenhouse are	How much growth? What is the plant doing? What does the plant like about the greenhouse? What does a greenhouse do?
7-8	Observe materials and explain their purpose, as well as the parts of the greenhouse Discuss the needs of a plant and what it does to satisfy them	What makes a greenhouse? What if a plant can't find water or light? What is different if the plant

	Quantifying the measured growth on a simple graph	were not in the greenhouse? How much growth, and graph.
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For the Greenhouse In A Bag activity, there is a lot of observation and talking about those observations. This will draw on students' knowledge of plants, and their reasoning with the observations they make. A writing response style assessment is very good for both. However, the relative young age of the students and the setting of the farm means that students are unlikely to be engaged with, and mostly unwilling to answer questions formally with writing, or spend a period of time writing. The solution for this is to give each student their own journal. This will allow the students to have a more personal and fun place for writing. The journals will also be the source of results and information to the teachers, showing how much each student learned.

- 3-4 year olds
 1. What is your greenhouse like?
 - a. Students should be able to talk about what it is made out of and what colors there are.
 - b. Students should be able to draw a picture of their greenhouse, using the corresponding colors.
 2. What do the plants get?
 - a. Students should be able to identify that the plant gets a place to live, water and maybe light.
 3. Draw a picture each day. What is different today?
 - a. Students should recognize when there is noticeable growth.
- 5-6 year olds
 1. What parts does a greenhouse have?
 - a. Students should be able to describe what the greenhouse is made of. They should recognize that the bag keeps water, air and the plant (and optionally soil) inside, and lets in sunlight.
 - b. Students should be able to draw a model of their greenhouse and label it with bag, water, sun(light), plant and air.
 2. What do plants need?
 - a. Students should recognize the needs of a plant, as addressed by the greenhouses. Light, water and space. The greenhouse provides a place for the plant to stay, keeping air and water inside for the plant, and letting light enter the bag because it is clear (see-through).
 3. How much has the plant grown? What is different?
 - a. Students should be able to measure how tall the plant is each day with a ruler. Students should be able to measure within a centimeter, but should try for smaller increments like halves of a centimeter.
 - b. Students should draw a picture each day and label what they see. Parts should be labelled as they form, such as the stem, roots, and leaves.

- 7-8 year olds
 1. What is a greenhouse?
 - a. Students should define a greenhouse in terms of its purpose, using their greenhouse bags to explain. They should recognize that it keeps plants safe in a place where all their needs are met, food (light, air) water and space.
 - b. When prompted with a comparison to the big greenhouse, they should recognize that it is warmer inside, and that plants can't grow when it is too cold.
 - c. Using these observations, students should draw a model of a greenhouse and label the parts and what they do. The bag or plastic walls keep the inside warm and retain the water, but also let in sunlight.
 2. How much has the plant grown? What is different?
 - a. Students should draw a picture each day and label what they see. Parts should be labelled as they form, such as the stem, roots, and leaves.
 - b. Students should be able to measure how tall the plant is each day within a half or quarter of a centimeter.
 - c. Students should keep a graph of the measurements, with height labelled on the 'y' axis and day on the 'x' axis. A bar or vertical line at each day interval on the graph will represent the height of the plant.
 - d. On the last day, students should write down how much the plant grew over how many days. They should note and times when the plant grew very quickly or very slowly.

I Can Eat A Whole Plant

Students assemble a model of a plant on a worksheet. The pieces needed are roots, seeds, leaves, stem, and flower. Produce including carrots, broccoli, celery, corn, and spinach as some options will be named and described before being placed on the corresponding spots of the worksheet.

	Development	Content
3-4	Simple observations such as color, texture and taste Recognizing different plant parts	What is this plant? What does it look like, feel like? Have you ever eaten it? What does it taste like? (at end of activity)
5-6	Recognizing different produce types and plant parts Using observations to state and prove the function of each part	What plant is this? What <i>part</i> is this? How do you know? What does it do?
7-8	Recognizing plant parts and functions	What plant is this? What part

	Using observations to state and prove the function of each part, as well as what growth stage the plant part is in or participates in Recognizing the difference in a plant life cycle versus that of other organisms	of the plant is it? What time does this part grow? When does the plant use it? How is the plant's life different from animals?
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The I Can Eat A Whole Plant activity already incorporates a performance assessment aspect through the worksheet, but functions more like a selected response assessment. It provides a way for students to demonstrate their knowledge of plant parts, by choosing which part does which function. This is a strong and simple way of demonstrating knowledge and reasoning, two developmental goals the activity is designed to expand upon.

- 3-4 year olds
 1. What is this plant?
 - a. Students should be able to name most of the produce (carrots, lettuce, broccoli, corn, sunflower seeds and celery. Radishes, spinach, cauliflower and asparagus are likely less-known, but should be learned if not already known.)
 2. What does it look like, feel like?
 - a. Students should describe in terms of colors, shape, and texture. Squishy, smooth, rough, bumpy, slippery, hard, soft are examples of shape terminology relevant to the age group. Shapes might include round, pointy, branches, flat or other such simple terms.
 3. Have you ever eaten it? What does it taste like?
 - a. Asking if students have eaten the produce before is mainly to convey the idea that many different parts of plants can be eaten. The taste can be described simply, students should be able to offer some sort of comparison, or describe what the flavor is like.
- 5-6 year olds
 1. What plant is this?
 - a. Students should strive to name each produce item. Less known items like radish and asparagus can be left out.
 2. What *part* is this? How do you know?
 - a. Students should use the appearance of the plant part to prove what part of the plant it is. Students may also note the appearance on the plant as evidence, such as the orange part of the carrot grows underground, so it must be a root.
 3. What does it do?
 - a. Students should combine knowledge of the plant part with their observations to describe the purpose of each part as they satisfy the needs of the plant.
- 7-8 year olds
 1. What plant is this? What part of the plant is it?
 - a. Students should be able to name the plant and part.

2. What time does this part grow? When does the plant use it?
 - a. Students should discuss the lifecycle of a plant to determine when each part is important. For example, roots are always important, so the plant can have water. Leaves are almost always important so the plant can make food. Seeds are important when the plant is ready to make more plants.
3. How is the plant's life different from animals? How are they the same?
 - a. Students should talk about differences between plant and animal lives such as plants needing other creatures like bees sometimes to help them make more plants. Students should note growth stages such as a baby animal and a seedling or sprout as the same stage.

Water Cycle In A Bag

Similar to the Greenhouse In A Bag, a plastic bag functions as an environmental model. Students will decorate a plastic bag with things relating to the water cycle, such as a sun, clouds, and the ground or a body of water. Then water, with optional food coloring (blue to make the water more noticable), is added to the bag. The bag should then have a small reservoir of water at the bottom. As it is hung on the side of the greenhouse or a window, the water will evaporate to the top, condense on the sides of the bag, and then drip back down. This cycle should be observed for around a week, long enough to see it happen multiple times. The students will observe the cycle and take notes.

	Development	Content
3-4	Making observations on a cyclical system Recognizing rain as a part of a cycle, and that the water in the clouds comes from somewhere on or below the ground/surface Recognize that weather changes day to day and season to season	What is the water at the bottom like? What are the drops at the top like? What about when they roll down? Is there always drops falling? If not, what are they doing? Is there always rain and clouds? Where do they go?
5-6	Recognize that the system in the bag models weather Show with observations how the water goes from one stage to another Compare the cycle in the bag to real weather Recognize the effect of temperature on the system, and where the change in temperature comes from Observe any effects coloring of the water has (if uncolored version exists to compare to)	What is the water at the bottom like? What are the drops like? What about when they fall? How does the bag feel when there are many drops? What about if there are few or no drops? What does it feel like outside

		when it rains? Why might that be?
7-8	<p>Recognize that the system in the bag models the water cycle and weather</p> <p>Use observations to prove what each stage the water takes on is</p> <p>Recognize that the sun powers the system</p> <p>Recognize that colored spots let less sun through, and any effect that has on the cycle in that particular place</p> <p>Recognize the effect of different seasons on weather</p>	<p>What does the water at the bottom represent?</p> <p>What do the drops represent?</p> <p>Where do they come from?</p> <p>Why does the bag get warm?</p> <p>How could the bag be kept colder? What would happen inside?</p>

Given the similarities to the Greenhouse In A Bag activity, Water Cycle In A Bag features a similar assessment method. As developing language skills is a large goal, much of the water cycle concepts will be expressed verbally. Students will observe the water cycle in the setup, and relate what they see to weather, particularly rain. Students will likely also have a journal in which to draw models and concepts.

- 3-4 year olds
 1. What is the water at the bottom like?
 - a. Students should suggest that the water resting at the bottom of the bag resembles or represents a body of water such as a pool, lake, puddle (etc).
 2. What are the drops at the top like? What about when they roll down?
 - a. This may not immediately be apparent to the younger students, but by first realizing that the drops rolling down like rain, they should be able to understand that the suspended drops represent clouds. Drawings of clouds on the bag should aid in conveying this.
 3. Is there always drops falling? If not, what are they doing?
 - a. Students should see that drops don't always fall.
 - b. Students should say that the drops are staying at the top or staying in the pool at the bottom
 4. Is there always rain and clouds? Where do they go?
 - a. Students should note that clouds go away eventually, and that the rain falls to the ground. This should then be related to the 'rain' in the bag falls down, and the 'clouds' disappear
 - b. Students should be able to draw the rain falling from clouds and onto the ground, and relate it to the bag
- 5-6 year olds
 1. What is the water at the bottom like?
 - a. Students should be able to suggest that it represents a body of water such as a pool, lake, ocean (etc)
 2. What are the drops like? What about when they fall?
 - a. Students should recognize that the drops are rain, staying up like clouds before falling back down.

3. How does the bag feel when there are many drops? What about if there are few or no drops?
 - a. Students should observe that when there are a lot of drops, the bag is warm. They should also see that when there are less drops, or smaller drops, the bag is colder.
 - b. Students should recognize that the sun makes the bag warm, and then more drops appear on the bag as a result.
 4. What does it feel like outside when it rains? Why might that be?
 - a. Students should note that it is cold when there is rain, and it is colder because the clouds block the sun.
 - b. Students should then be able to draw a simple model of the water cycle, where water starts in the clouds, falling when it is cold, and returning to bodies of water, before rising again to the clouds when it is warm.
- 7-8 year olds
1. What does the water at the bottom represent?
 - a. Students should recognize that the water represents a body of water like a pool, pond, ocean (etc).
 2. What do the drops represent?
 - a. Students should recognize that the drops represent clouds and rain.
 3. Where do they come?
 - a. Students should recognize that the drops came from the water at the bottom of the bag.
 4. Why does the bag get warm?
 - a. Students should note that the sun warms up the bag, and that drops then appear on the bag.
 5. How could the bag be kept colder? What would happen inside?
 - a. Students should suggest some ways to block the sunlight. Methods of keeping the bag cool such as adding ice are acceptable as well. But any method of blocking sunlight is ideal, as it is like clouds blocking the sun.
 - b. Students should then draw the water cycle, labelling a body of water, clouds and rain. They should be instructed to label each part, as well as the temperature (hot, cold, or regular) for the part that rains, as well as the part for the water returning to clouds. They should relate from the previous question that cold temperatures correspond with rain, and hot for water forming clouds.

Spouting Water

For older students (9-13). Students will observe how water exits holes in a large water bottle, each hole below the previous. This helps convey the concept of pressure. The bottle will be filled with the holes covered first, and the holes will be uncovered at the same time after students make predictions about how the water will flow out.

	Development	Content
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9-10	Students can make predictions about the flow	Which hole will most of the water flow out of? Why?
11-13	Using knowledge about gravity, students can make predictions about the flow	Which hole will most of the water flow out of, with gravity pulling the water down? What effect does gravity have on the water?

- 9-10 year olds
 1. Which hole will most of the water flow out of?
 - a. Students should offer predictions with some reason behind their statement.
 2. Why?
 - a. Students should consider the weight of the water, or that when the water level falls below the first hole, that hole won't have any flow out of it.
 - b. After the experiment is conducted, students should reevaluate their predictions knowing that the weight of water pushes down, resulting in more pressure towards the bottom of the bottle.
- 11-13 year olds
 1. Which hole will most of the water flow out of, with gravity pulling the water down?
 - a. Students should make predictions about which hole will have the most flow, taking gravity into account, or the weight of the water.
 2. What effect does gravity have on the water?
 - a. Students should elaborate on their predictions, explaining that gravity pulls everything downwards, so the water on top is pulled down on the water on the bottom, so the water on the bottom is being pushed on the most.

How Plants Absorb Water

This activity uses colored water and celery to show students how plants draw up water and what they do with it. As the celery takes in the colored water, the plant takes on the color. Places in the plant that receives more water change color more.

	Development	Content
3-4	Students can name colors Students recognize the need for water	What color is the water? What color is the plant turning? What is happening to the

		water, then?
5-6	Students recognize where plants store more water based on the observed color Students recognize that the plant actively takes in water to grow	What happened to the plant? How did it become the same color as the water? What parts have more color? Why?
7-8	Students recognize that the plant adopts the color of the water by drawing it in Students note other changes, specifically any growth	Where is the water going? Why? What parts keep the most water? Why?

- 3-4 year olds
 1. What color is the water?
 - a. Students should name the colors correctly.
 2. What color is the plant turning?
 - a. Students should correctly name the colors, matching to the colored water the plant is in.
 3. What is happening to the water, then?
 - a. Students should infer that the water is going into the plant, because plants need or “like” water.
- 5-6 year olds
 1. What happened to the plant?
 - a. Students should explain that the plant turned the same color as the water.
 2. How did it become the same color as the water?
 - a. Students should say that the plant takes in the water, so it also took in the color.
 3. What parts have more color? Why?
 - a. Students should state what parts have more color based on observations, and suggest that the parts with more color must have more water, or need more water.
- 7-8 year olds
 1. Where is the water going?
 - a. Students should note that the water is going up into the plant, as the plant changed color to match water.
 2. Why?
 - a. Students should be able to answer this by talking about plant parts, and their purposes Roots bring up the water through the stems up into the leaves (etc).
 3. What parts keep the most water? Why?
 - a. Students should note which parts are the most colored through observation, and say that those parts must receive the most water and therefore the most color.

Propagation of a Plant

This activity is mostly observational. Prepared stock plants are left in a container with some water and soilless potting mix, and students record their observations in a journal.

	Development	Content
3-4	Students recognize plant growth and plant parts Students learn estimation skills using simple comparisons	What parts are there at the start? What parts are there at the end? How big did it get?
5-6	Students recognize growth and development Students understand plant needs and how plants satisfy those needs Students learn measurement skills using tools and comparisons (such as a finger length)	What parts are there at the start? What parts developed first? How big did it get?
7-8	Students recognize plant parts and the process of plant growth Students learn measurement skills with tools	What parts are there at the start? What parts developed first? Why those parts first? How much taller did the plant grow?

- 3-4 year olds
 1. What parts are there at the start?
 - a. Students should name what plant parts they can see at the start (stem, leaves, etc)
 2. What parts are there at the end?
 - a. Students should note what parts developed, such as roots, flowers (etc). These should be recognizable parts that weren't there at the beginning of the activity,
 3. How big did it get?
 - a. Using a simple comparison such as the size of a student's hand or fingers, students should express the difference in height. This should be aided by journal drawings (or potentially pictures).
 - b. Students should track the growth through drawings in a journal, to record what parts grew when.
- 5-6 year olds
 1. What parts are there at the start?
 - a. Students should name the plant parts observed at the start.
 2. What parts developed first?
 - a. As new parts develop or grow, students should make notes in their

journals. Students should be able to label these parts on a drawing and describe their purpose.

3. How big did it get?
 - a. Using rulers and simple comparisons like the size of a finger, students should track the plants growth.
- 7-8 year olds
 1. What parts are there at the start?
 - a. Students should name all the plant parts present at the start.
 2. What parts developed first?
 - a. As parts develop, students should label them in diagrams in their journals
 3. Why those parts first?
 - a. Students should cite plant needs when discussing why the plant grew the new parts. Reasons should come in the form of the plant satisfying a need or function.
 4. How much taller did the plant grow?
 - a. Students should measure growth with a ruler for each journal entry, making a graph at the last day with height on the 'y' axis and time in days on the 'x' axis.

5.0 Conclusion

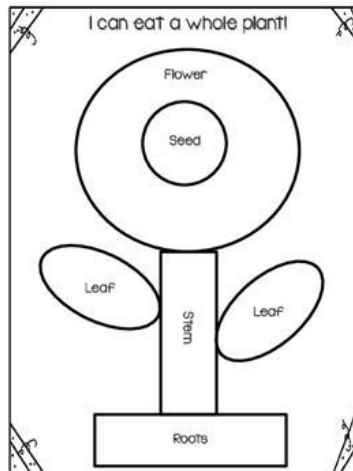
In this section we will discuss the final designs of our project with their limitations. Additionally, you will find the next steps which will help to address the limitations. Finally, we will discuss the significance of our project.

5.1 Final Designs

The goal of this project was to design and build a rainwater catchment system off the greenhouse, as well as develop STEM-based educational activities surrounding the greenhouse. Several activities were created for use on the farm. Each of these activities were geared towards fulfilling Massachusetts Department of Education standards appropriate for the age group of the children who participate in TBT's programs. These activities include Greenhouse in a Bag and I Can Eat a Whole Plant which can be seen below.



Greenhouse in a Bag



I Can Eat a Whole Plant

Along with each activity there are materials in order to help the educator facilitate the activity. This includes an outline of the learning goals and objectives as well as the materials and general timeline of each of these activities. This material can be seen below.

Greenhouse in a Bag

Description: Lesson on how greenhouses work. Each student will make a mini greenhouse out of a plastic bag and grow beans on the inside. Each student will make observations on the growth in their own journal. Only takes three to five days for the beans to start to grow.

Procedure: First step is to make a paper greenhouse frame. This is not required, but is aesthetically pleasing.

Education, which are standards prepared by the commissioner, Mitchell D. Chester, Ed.D. and is used for the Commonwealth's public schools to ensure students are prepared for success in college, career, and civic life.

Age Group (years)	3-4 (Pre-K)	5-6 (Kindergarten-1st)	7-8 (2nd-3rd)
Developmental Goals	<ul style="list-style-type: none">Students sort materials by simple observable properties such as texture and colorStudents share their understanding of these concepts through discussion as they develop their language and quantitative skills.	<ul style="list-style-type: none">Students will learn to use observations as evidence to support a claim through growing language skills.	<ul style="list-style-type: none">Students use their observational skills gained in earlier grades to classify materials based on similar properties and functions.Students gain experience testing different materials to collect and then analyze data for the purpose of determining which materials are best for a specific function
Learning Goals	<ul style="list-style-type: none">Use observations to explain the young plants and animals are like but not exactly like their parents (PreK-LS3-1-MA, 2016).Use observations to recognize differences and similarities among themselves and their friends (PreK-LS3-2-MA, 2016).	<ul style="list-style-type: none">Observe and communicate that animals and plants need food, water and air to survive. Plants make their own food and need light to live and grow (K-LS1-1, 2016).Recognize that all plants and animals grow and change over time (K-LS1-2-MA, 2016).Conduct an investigation to determine the effect of placing materials that allow light to pass through them, allow only some light through them block all of the light or redirect light when put in the path of a beam of light (1-PS4-3, 2016).	<ul style="list-style-type: none">Describe and classify different kinds of materials by observable properties of color, flexibility, hardness, texture absorbency (2-PS1-1, 2016).Analyze data from tests of two objects designed to solve the same design problem to compare the strengths and weaknesses of how each object performs (K-2-ETS1-3, 2016).

Table 1: Learning and Developmental Outcomes for Greenhouse in a Bag Activity

Educational Activity Outline/Description

Additionally, for each educational activity, assessment rubrics were created to give teachers and facilitators a guide of what the students should learn. The rubrics account for age group, as well as the learning goals set by national and state education standards.

	Development	Content
3-4	<p>Making observations on a cyclical system</p> <p>Recognizing rain as a part of a cycle, and that the water in the clouds comes from somewhere on or below the ground/surface</p> <p>Recognize that weather changes day to day and season to season</p>	<p>What is the water at the bottom like?</p> <p>What are the drops at the top like? What about when they roll down?</p> <p>Is there always drops falling?</p> <p>If not, what are they doing?</p> <p>Is there always rain and clouds? Where do they go?</p>
5-6	<p>Recognize that the system in the bag models weather</p> <p>Show with observations how the water goes from one stage to another</p> <p>Compare the cycle in the bag to real weather</p> <p>Recognize the effect of temperature on the system, and where the change in temperature comes from</p> <p>Observe any effects coloring of the water has (if uncolored version exists to compare to)</p>	<p>What is the water at the bottom like?</p> <p>What are the drops like?</p> <p>What about when they fall?</p> <p>How does the bag feel when there are many drops? What about if there are few or no drops?</p> <p>What does it feel like outside when it rains? Why might that be?</p>
7-8	<p>Recognize that the system in the bag models the water cycle and weather</p> <p>Use observations to prove what each stage the water takes on is</p> <p>Recognize that the sun powers the system</p> <p>Recognize that colored spots let less sun through, and any effect that has on the cycle in that particular place</p> <p>Recognize the effect of different seasons on weather</p>	<p>What does the water at the bottom represent?</p> <p>What do the drops represent?</p> <p>Where do they come from?</p> <p>Why does the bag get warm?</p> <p>How could the bag be kept colder? What would happen inside?</p>

Assessment Rubric

When designing the rainwater catchment system we followed the Engineering Design Process. This process includes the following steps: Defining the problem, brainstorming, creating, and testing and improving(May 2017). We have completed the first four steps for the rainwater catchment system: 1. The problem of water resilience, 2. brainstorming possible watering systems, 3. designing a rainwater catchment system off of the greenhouse, and 4. built said system. Our final design can be seen below.



Final Design at Turn Back Time

However, in order to fulfill the entire design process we need to assess and make improvements on our design, which leads to our limitations due to time constraints.

5.2 Limitations

Our final project was limited due to time constraints and changes in the project sponsors expectations. Unfortunately, we were unable to revise our system to make the system more efficient and effective. Additionally, the lack of internal design of the greenhouse made it so the water delivery system could not be implemented into the greenhouse.

Secondly our educational activities were also affected by the time constraints. We were unable to construct and implement the educational activities and their associated assessments.

5.3 Next Steps

For this project, the next step would be to implement and assess the educational components for effectiveness and assess the rainwater catchment system. We recommend that our sponsor Lisa implement the activities we designed, and use our assessment material to determine if the activity meets the learning goals for the children on the farm. We also

recommend that during the activity they make observations to identify any unpredicted learning outcomes. After evaluation we recommended that Lisa revise the activities and reassess. They can then continue the reassessment of these activities to meet the programs changing needs.

As for the rainwater catchment system, we recommend once the interior of the greenhouse is designed and built that it be equipped with the water delivery methods mentioned previously. Additionally, we recommended Lisa regularly assess the water capture and storage system to improve the system and finish the engineering design process. Furthermore, we recommend Lisa look into attaching the gutter to the greenhouse to allow the system to capture more water and therefore be better suited for its goal, to be the primary water source for the greenhouse. Proper procedure for attaching the gutters can be found above.

5.4 Project Significance

We designed a rainwater catchment system on the greenhouse at TBT farm. This system ensures that TBT can have a functioning greenhouse that can extend growing and learning opportunities. The additional water source can also increase TBT's resilience in the face of drought. Increased resilience will allow turn back time to continue to offer the educational programs and opportunities that have proven to develop physical, mental, and cognitive benefits to children. The increase in growing season will allow Turn Back Time to be more fruitful, and provide the farm with more area for educational activities in the winter months. The implementation of our system will allow Turn Back Time farm to do a better job achieving their mission statement. This project allowed us to implement some of the topics we have learned in the classroom to real world projects. Additionally, it gave us experience working with a client on a project, which had continuously changing results.

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Appendix A

Pump Calculations

Given PUMP data:

Maximum Head 30 Feet = h

12 GPM @ 90 strokes per min = q

Water - 62.4 lb/ft³

Gravity 32.2 ft/s²

$$P_{h(kW)} = q \rho g h / (3.6 \cdot 10^6)$$

where

$P_{h(kW)}$ = hydraulic power (kW)

q - flow capacity (gpm)

γ - specific weight of fluid (lb/ft³)

g - gravity (ft/s²)

h - differential head (ft)

Hydraulic Power = .07 kW = .09hp = 77.159 N*m/s

Given CHILDREN data:

2-5-year-olds Force : male = 59.65N female = 76.43N

<https://www.humanics-es.com/strength.pdf>

90 strokes per minute for max flow rate

Assuming each pump full stroke is 1ft of movement (6 inches up 6 inches down)

90ft/min

Torque = Force * Radius

Assuming the force Applied is normal (90 degrees) to the lever

60N * .3 meters = 13 N*m per pump

Increasing the length of the lever will increase torque and allow the children to get the same result with less force.

The force which a child can apply is more than what is required by the pump.

Appendix B

Wind Calculations

$$q_z = 0.00256 * k_z * k_{zt} * k_d * V^2 * I$$

q_z = velocity pressure

k_z = velocity pressure exposure coefficient

k_{zt} = topographical factor

k_d = wind directional factor

V = wind speed (mph)

I = importance factor

$$q_z = 0.00256 * k_z * k_{zt} * k_d * V^2 * I = 24.57 \text{ lb/ft}^2$$

Velocity Pressure as a point load for wind

$$F = q_z * G * c_f * A$$

F = force on face of gutter

q_z = velocity pressure from above

G = gust factor

c_f = force coefficient

A = area of the face of the gutter

$$F = q_z * G * c_f * A = 292.34 \text{ pounds}$$

Snow Calculations

$$p_f = 0.7C_eC_tI_s p_g$$

p_f = force from snow

C_e = exposure factor

C_t = thermal factor

I_s = importance factor

p_g = ground snow load

$$p_f = 0.7C_eC_tI_s p_g = 304.92 \text{ lbs}$$

All variables except for wind speed and ground snow load can be found in the American Society of Civil Engineers journal 7-10. Wind speed and ground snow load were taken from the Massachusetts Commonwealth website.

Appendix C

Greenhouse in a Bag activity assessment

	Development	Content
3-4	Simple observations like color and texture Fine motor skills for arts and crafts Recognizing what makes plants different	What are the colors, shapes and textures? What do plants like?
5-6	Observing and comparing Measuring growth Making a claim about the plant's progress, using observations to support it Discuss what the parts of a greenhouse are	How much growth? What is the plant doing? What does the plant like about the greenhouse? What does a greenhouse do?
7-8	Observe materials and explain their purpose, as well as the parts of the greenhouse Discuss the needs of a plant and what it does to satisfy them Quantifying the measured growth on a simple graph	What makes a greenhouse? What if a plant can't find water or light? What is different if the plant were not in the greenhouse? How much growth, and graph.

- 3-4 year olds
 1. What is your greenhouse like?
 - a. Students should be able to talk about what it is made out of and what colors there are.
 - b. Students should be able to draw a picture of their greenhouse, using the corresponding colors.
 2. What do the plants get?
 - a. Students should be able to identify that the plant gets a place to live, water and maybe light.
 3. Draw a picture each day. What is different today?
 - a. Students should recognize when there is noticeable growth.
- 5-6 year olds
 1. What parts does a greenhouse have?
 - a. Students should be able to describe what the greenhouse is made of. They should recognize that the bag keeps water, air and the plant (and optionally soil) inside, and lets in sunlight.
 - b. Students should be able to draw a model of their greenhouse and label it with bag, water, sun(light), plant and air.

2. What do plants need?
 - a. Students should recognize the needs of a plant, as addressed by the greenhouses. Light, water and space. The greenhouse provides a place for the plant to stay, keeping air and water inside for the plant, and letting light enter the bag because it is clear (see-through).
 3. How much has the plant grown? What is different?
 - a. Students should be able to measure how tall the plant is each day with a ruler. Students should be able to measure within a centimeter, but should try for smaller increments like halves of a centimeter.
 - b. Students should draw a picture each day and label what they see. Parts should be labelled as they form, such as the stem, roots, and leaves.
- 7-8 year olds
1. What is a greenhouse?
 - a. Students should define a greenhouse in terms of its purpose, using their greenhouse bags to explain. They should recognize that it keeps plants safe in a place where all their needs are met, food (light, air) water and space.
 - b. When prompted with a comparison to the big greenhouse, they should recognize that it is warmer inside, and that plants can't grow when it is too cold.
 - c. Using these observations, students should draw a model of a greenhouse and label the parts and what they do. The bag or plastic walls keep the inside warm and retain the water, but also let in sunlight.
 2. How much has the plant grown? What is different?
 - a. Students should draw a picture each day and label what they see. Parts should be labelled as they form, such as the stem, roots, and leaves.
 - b. Students should be able to measure how tall the plant is each day within a half or quarter of a centimeter.
 - c. Students should keep a graph of the measurements, with height labelled on the 'y' axis and day on the 'x' axis. A bar or vertical line at each day interval on the graph will represent the height of the plant.
 - d. On the last day, students should write down how much the plant grew over how many days. They should note and times when the plant grew very quickly or very slowly.